

TITLE OF THE INVENTION

OPTICAL AMPLIFYING DEVICE

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BACKGROUND OF THE INVENTION

5 Field of the Invention

[0001] The present invention relates to optical amplifying devices for amplifying an input optical signal and, more specifically, to an optical amplifying device suitable for use in amplifying a burst optical signal.

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Description of the Background Art

[0002] As well known, when intermittently-inputted optical signals (hereinafter referred to as burst optical signals) are amplified through a general optical fiber amplifier, for example, 15 waveform degradation, called optical surges, occurs in the optical signals. Optical surges are now briefly described with reference to the accompanying drawings.

[0003] Optical surges are caused by transient response of optical amplifiers. How much the input optical signal is degraded 20 in waveform depends on the characteristics of the optical amplifier, such as a relaxation time constant. Waveform degradation also depends on the input optical signal itself. As the input light varies in power, the waveform becomes degraded.

[0004] FIG. 18a shows the waveform of an optical signal when 25 the amount of data traffic is small and data is intermittently

transmitted, such as a case where data packets are spaced long. If such burst optical signal as shown in FIG. 18a is provided to an optical amplifier, temporary periods during which no data is provided at all are observed, which are hereinafter referred to 5 as no-data period. If an optical signal is provided after a long no-data period, input light optical power varies. Therefore, as shown in FIG. 18b, the optical signal after amplification is instantaneously increased in level (optical surges), thereby causing degradation in waveform.

10 [0005] Such waveform degradation in a transmission system makes it difficult for a receiving side to always optimally identify data. Thus, optical surges have to be suppressed. From this viewpoint, one optical amplifying device capable of carrying out optical amplification while suppressing optical surges is 15 disclosed in Japanese Patent Laid-Open Publication No. 11-135862 (1999-135862). This conventional optical amplifying device (hereinafter referred to as conventional device) is described below with reference to the drawings.

10 [0006] As shown in FIG. 19, a conventional device 9000 is provided with an input optical signal of a wavelength  $\lambda 1$  as shown in FIG. 20a. The provided optical signal is branched into two by an optical brancher 910. One branched optical signal goes through an optical receiver 920, an inverting amplifier 940, and a light source 924, thereby being converted into an optical signal 25 of a wavelength  $\lambda d$  with its logic level inverted, as shown in

FIG. 20b. Then, the converted optical signal is multiplexed with the other optical signal branched by the optical brancher 910. The optical signal after such multiplexing is constant in optical power, as shown in FIG. 20c.

5 [0007] The optical signal after multiplexing is amplified by an optical fiber amplifier 916. At this time, optical surges do not occur since the input light is constant in optical power. The amplified optical signal is provided to an optical filter 918, wherein the optical signal of the wavelength  $\lambda 1$  is passed through.

10 [0008] As such, according to the conventional device 9000, the input optical signal is superposed with a dummy optical signal differed in wavelength. Thus, the input light provided to the amplifier 916 can become temporarily constant in optical power. In this way, optical amplification can be carried while optical 15 surges are suppressed.

[0009] As stated above, in the conventional device, the input optical signal is superposed with the dummy optical signal, and then provided to the amplifier. Therefore, the optical signal provided to the amplifier becomes larger in optical power on 20 average than the input optical signal. In general, amplification gain of the amplifier varies according to the average optical power of the optical signal provided to the amplifier. The larger the optical power of the input light is, the less the amplification gain is. Therefore, in the conventional device, the 25 amplification gain of the amplifier is disadvantageously reduced.

[0010] Moreover, the conventional device has to accurately detect data provided at a higher bit rate such as 10 gigabits/second for logic level inversion. Accordingly, the electrical load on the conventional device is increased. This 5 increase leads to a degradation in device's performance and an increase in cost.

[0011] Also, a large number of components are required for the conventional device. Thus, the conventional device is complex in structure.

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#### SUMMARY OF THE INVENTION

[0012] Therefore, one object of the present invention is to provide an optical amplifying device capable of carrying out optical amplification while suppressing optical surges and also 15 preventing reduction in amplification gain of an amplifier. A further object of the present invention is to provide an optical amplifying device capable of carrying out optical amplification while suppressing optical surges without requiring a large-load electrical process. A still further object of the present 20 invention is to provide an optical amplifying device capable of carrying out optical amplification while suppressing optical surges in a simple structure.

[0013] The present invention has the following features to achieve the objects above.

25 [0014] A first aspect of the present invention is directed

to an optical amplifying device for amplifying an input optical signal, the device comprising:

a control electrical signal generator for generating a control electrical signal having a waveform obtained by inverting  
5 an envelope of the input optical signal;

a light-emitter for outputting, based on the control electrical signal, a dummy optical signal having a wavelength that is different from a wavelength of the input optical signal;

10 a multiplexer for multiplexing the input optical signal and the dummy optical signal;

an amplifier for amplifying a multiplexed optical signal;  
and

a separator for separating at least the input optical signal from an optical signal after amplification by the amplifier.

15 [0015] As described above, in the first aspect, the input optical signal is multiplexed with the dummy optical signal having a waveform obtained by inverting the envelope of the input optical signal. Thus, optical amplification can be carried out without waveform degradation.

20 [0016] A second aspect of the present invention is directed to an optical amplifying device for amplifying an input optical signal, the device comprising:

a light-emitter for transmitting the input optical signal, and emitting, based on the optical signal transmitted by the  
25 light-emitter, a dummy optical signal having a waveform obtained

by inverting a waveform of the input optical signal and having a wavelength that is different from a wavelength of the input optical signal;

5 a controller for controlling the wavelength of the dummy optical signal emitted from the light-emitter;

an amplifier for amplifying the optical signal and the dummy optical signal from the light-emitter; and

10 a separator for separating the input optical signal from an optical signal after amplification.

15 [0017] As described above, in the second aspect, by being transmitted through the light-emitter, the optical signal is multiplexed with the dummy optical signal having the waveform obtained by inverting the waveform of the input optical signal. Thus, optical amplification can be carried out in a more simplified structure without optical surges.

20 [0018] These and other objects, features, aspects and advantages of the present invention will become more apparent from the following detailed description of the present invention when taken in conjunction with the accompanying drawings.

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#### BRIEF DESCRIPTION OF THE DRAWINGS

[0019] FIG. 1 is a block diagram showing the structure of an optical amplifying device 1000 according to a first embodiment of the present invention;

25 FIGS. 2a to 2d are diagrams showing waveforms of optical

signals in the optical amplifying device 1000;

FIGS. 3a and 3b are diagrams in assistance of explaining the operation of an optical filter 118;

FIG. 4 is a block diagram showing the structure of a system 5 using an optical amplifying device 1500, which is one modification of the optical amplifying device 1000;

FIG. 5 is a block diagram showing the structure of an optical amplifying device 2000 according to a second embodiment of the present invention;

FIGS. 6a to 6d are diagrams showing waveforms of optical signals in the optical amplifying device 2000;

FIG. 7 is a block diagram showing the structure of an optical amplifying device 3000 according to a third embodiment of the present invention;

FIGS. 8a to 8d are diagrams showing waveforms of optical signals in the optical amplifying device 3000;

FIG. 9 is a block diagram showing the structure of an optical amplifying device 4000 according to a fourth embodiment of the present invention;

FIGS. 10a and 10b are diagrams showing waveforms of optical signals in the optical amplifying device 4000;

FIG. 11 is a block diagram showing the structure of an optical amplifying device 5000 according to a fifth embodiment of the present invention;

FIGS. 12a to 12c are diagrams showing waveforms of optical

signals in the optical amplifying device 5000;

FIGS. 13a and 13b are diagrams in assistance of explaining the operation of a first optical router 536;

FIG. 14 is a block diagram showing the structure of an 5 optical transmission system using the optical amplifying device 5000;

FIG. 15 is a block diagram showing the structure of an optical amplifying device 6000 according to a sixth embodiment of the present invention;

10 FIG. 16 is a block diagram showing the structure of an optical transmission system according to a seventh embodiment of the present invention;

FIGS. 17a and 17b are diagrams in assistance of explaining the operation of a second optical router 736;

15 FIGS. 18a and 18b are diagrams in assistance of explaining optical surges that occur when a burst optical signal is amplified;

FIG. 19 is a block diagram showing the structure of a conventional optical amplifying device 9000; and

20 FIGS. 20a to 20c are diagrams showing waveforms of optical signals in the conventional optical amplifying device 9000.

#### DESCRIPTION OF THE PREFERRED EMBODIMENTS

[0020] The embodiments of the present invention are 25 described below with reference to the drawings.

(First Embodiment)

[0021] FIG. 1 is a block diagram showing the structure of an optical amplifying device according to a first embodiment of the present invention. An optical amplifying device 1000 includes an optical brancher 110, a delay unit 112, an optical multiplexer 114, an optical amplifier 116, an optical filter 118, an optical detector 120, a first controller 122, and an optical signal generator 124. With reference to FIGS. 1, 2a to 2d, 3a, and 3b, the operation of the optical amplifying device according to the present embodiment is now described.

[0022] The optical amplifying device 1000 is provided with an input optical signal having a waveform  $\lambda_1$  and an amplitude  $\alpha$ . This optical signal carries burst-like binary digital data. FIG. 2a shows the waveform of this optical signal. In FIG. 2a, a period during which binary digital data is carried on the optical signal is referred to as a data period, while a period during which no binary digital data is carried thereon is referred to as a no-data period. A dotted line indicates an envelope of the optical signal.

[0023] The optical brancher 110 branches the received optical signal into two. The optical detector 120 converts one optical signal outputted from the optical brancher 110 into an electrical signal. The first controller 122 generates a control electrical signal having a waveform obtained by inverting the envelope of the electrical signal. Based on this control

electrical signal, the optical signal generator 124 produces a dummy optical signal having a waveform  $\lambda d$  and an amplitude  $\alpha / 2$ . FIG. 2b shows the waveform of the dummy optical signal.

[0024] On the other hand, the other optical signal outputted 5 from the optical brancher 110 is delayed by the delay unit 112 for a predetermined time, and then forwarded to the optical multiplexer 114. Here, the predetermined time is a time required for the one optical signal outputted from the optical brancher 110 to go through the optical detector 120, the first controller 10 122, and then the optical signal generator 124 to become the dummy optical signal. The optical multiplexer 114 multiplexes the optical signal from the delay unit 112 and the dummy optical signal from the optical signal generator 124 together, and then produces a multiplexed optical signal. FIG. 2c shows the waveform of the 15 multiplexed optical signal.

[0025] The optical amplifier 116 amplifies the multiplexed optical signal. At this time, as shown in FIG. 2c, the multiplexed optical signal is always at  $\alpha / 2$  in level during the no-data periods during which transmission data does not exist, and also 20 at  $\alpha / 2$  in average during the data periods during which transmission data exists. Therefore, the optical signal provided to the optical amplifier 116 is approximately constant in optical power, and is not degraded in waveform when amplified.

[0026] The optical filter 118 has such a transmittance 25 characteristic as shown in FIG. 3a to separate the optical signal

of the wavelength  $\lambda_1$  from the amplified optical signal having a spectrum as shown in FIG. 3b. FIG. 2d shows the waveform of the passed optical signal.

[0027] As described above, in the first embodiment, the 5 optical signal having the wavelength  $\lambda_1$  and the amplitude  $\alpha$  to be amplified is multiplexed with the dummy optical signal having the wavelength  $\lambda_d$  ( $\neq \lambda_1$ ) and the amplitude  $\alpha/2$  obtained by inverting the envelope of the input optical signal. Thus, optical amplification can be carried out without waveform degradation. 10 Furthermore, the average optical power of the optical signal provided to the optical amplifier 116 is cut in half, compared with that in the conventional device as shown in FIG. 19. Therefore, higher amplification gain can be achieved. Still further, the control electrical signal outputted from the first 15 controller 122 is generated based on the envelope of the input optical signal. Thus, the present optical amplifying device is less electrically loaded than the conventional device shown in FIG. 19.

[0028] In the present embodiment, the dummy optical signal 20 is one-half in amplitude of the input optical signal, but is not necessarily restricted to the above. For making the optical power to the optical amplifier 116 more constant, however, one-half the amplitude of the input optical signal is preferable, as in the present embodiment.

25 [0029] Furthermore, in the present embodiment, the input

optical signal is a burst optical signal. Alternatively, an arbitrary optical signal can be amplified.

[0030] Still further, in the present embodiment, the input optical signal has a single wavelength, that is, only the 5 wavelength  $\lambda_1$ . Similarly, if optical signals with different wavelengths  $\lambda_1$  to  $\lambda_n$  are provided in a time-division manner, for example, these optical signals can be amplified without degradation in waveform. In this case, however, the wavelength  $\lambda_d$  of the dummy optical signal has to be different from any of 10 the wavelengths  $\lambda_1$  to  $\lambda_n$ .

[0031] Still further, in the present embodiment, the optical filter 118 is used for the purpose of separating the optical signal of the wavelength  $\lambda_1$  from the amplified optical signal. Alternatively, an optical router may be used to achieve the same 15 purpose.

[0032] In the present embodiment, the input optical signal is converted by the optical detector 120 into an electrical signal, and the control electrical signal is generated by the first controller 122 based on this electrical signal. Alternatively, 20 for example, the control electrical signal may be generated based on an electrical signal to be carried on the input optical signal. Such modification example of the present embodiment is briefly described with reference to FIG. 4. In FIG. 4, components identical in structure to those in FIG. 1 are provided with the 25 same reference numerals.

[0033] In FIG. 4, a data unit 10 produces an electrical signal carrying burst-like binary digital data. This electrical signal is converted by an optical signal generator 20 into an optical signal having a wavelength  $\lambda_1$ . The optical signal is provided 5 to an optical amplifying device 1500 as the input optical signal.

[0034] The electrical signal from the data unit 10 is also provided to the first controller 122 in the optical amplifying device 1500. As in the optical amplifying device 1000 shown in FIG. 1, the first controller 122 provides the optical signal 10 generator 124 with a control electrical signal having a waveform obtained by inverting the waveform of the electrical signal.

[0035] The optical signal generator 124 generates a dummy optical signal based on the control electrical signal. The optical multiplexer 124 multiplexes the input optical signal 15 coming through the delay unit 112 and the dummy optical signal together. Thereafter, the operation of the optical amplifying device 1500 is the same as that of the optical amplifying device 1000 shown in FIG. 1, and therefore not described herein. As such, in the optical amplifying device 1500 according to this 20 modification example, the same effects can be achieved as those in the optical amplifying device 1000 shown in FIG. 1.

[0036] (Second embodiment)

FIG. 5 is a block diagram showing the structure of an optical amplifying device according to a second embodiment of the present 25 invention. An optical amplifying device 2000 includes the

optical brancher 110, the delay unit 112, the optical multiplexer 114, the optical amplifier 116, the optical filter 118, a logic level determination unit 226, a second controller 228, and the optical signal generator 124. Note that, in FIG. 5, components 5 identical in structure to those in FIG. 1 are provided with the same reference numerals. With reference to FIGS. 5 and 6a to 6d, the operation of the optical amplifying device according to the second embodiment is described below.

[0037] The optical amplifying device 2000 is provided with 10 an input optical signal having a waveform  $\lambda_1$  and an amplitude  $\alpha$ . This optical signal carries burst-like binary digital data. FIG. 6a shows the waveform of this optical signal. In FIG. 6a, a period during which binary digital data is carried on the optical signal is referred to as a data period, while a period during which 15 no binary digital data is carried thereon is referred to as a no-data period.

[0038] The optical brancher 110 branches the received optical signal into two. The logic level determination unit 226 determines the level of the binary digital data carried on one 20 optical signal outputted from the optical brancher 110. The second controller 228 generates a control electrical signal based on a determination made by the logic level determination unit 226. This control electrical signal becomes  $\alpha/2$  in level from 0, for example, when the logic level determination unit 226 determines 25 that the value of the digital data continuously indicates 0 for

more than a predetermined time  $A_1$ , and returns to "0" when the value of the digital data becomes 1. The time  $A_1$  is predetermined based on physical characteristics of the optical amplifier 116, such as a relaxation time constant, and other factors. Based on 5 this control electrical signal, the optical signal generator 124 produces a dummy optical signal having the wavelength  $\lambda_d$  and the amplitude  $\alpha/2$ . FIG. 6b shows the waveform of this dummy optical signal.

**[0039]** On the other hand, the other optical signal outputted 10 from the optical brancher 110 is delayed by the delay unit 112 for a predetermined time, and then forwarded to the optical multiplexer 114. Here, the predetermined time is a time required for the one optical signal outputted from the optical brancher 110 to go through the logic level determination unit 226, the 15 second controller 228, and then the optical signal generator 124 to become the dummy optical signal. The optical multiplexer 114 multiplexes the optical signal from the delay unit 112 and the dummy optical signal from the optical signal generator 124 together, and then produces a multiplexed optical signal. FIG. 20 6c shows the waveform of the multiplexed optical signal.

**[0040]** The effects of optical surges that occur when the input optical signal is changed in level from 0 to  $\alpha$  become larger as the period at the level 0 before the change is longer. Therefore, if the no-data period continues for more than the 25 predetermined time  $A_1$ , the input optical signal is multiplexed

with the dummy optical signal so that the no-data period of the multiplexed optical signal provided to the optical amplifier 116 does not continue for more than the time  $A_1$ . Thus, the effects of optical surges at amplification can be suppressed within a 5 permissible range.

[0041] The optical amplifier 116 amplifies the multiplexed optical signal. At this time, as shown in FIG. 6c, a period during which the multiplexed optical signal is at the "0" level is, at most, the time  $A_1$ .

10 [0042] After amplification, similarly to the first embodiment, the optical filter 118 separates the optical signal having the wavelength  $\lambda_1$  from the amplified optical signal. FIG. 6d shows the waveform of the separated optical signal.

15 [0043] As described above, according to the second embodiment, the no-data period of the multiplexed optical signal provided to the optical amplifier 116 is controlled so as to become, at most, the time  $A_1$ . Thus, the effects of optical surges at amplification can be suppressed within a permissible range. Moreover, the average optical power of the optical signal provided 20 to the optical amplifier 116 is smaller than that in the conventional device shown in FIG. 19. Thus, more amplification gain can be obtained.

[0044] (Third Embodiment)

25 FIG. 7 is a block diagram showing the structure of an optical amplifying device according to a third embodiment of the present

invention. An optical amplifying device 3000 includes the optical brancher 110, the delay unit 112, the optical multiplexer 114, the optical amplifier 116, the optical filter 118, the logic level determination unit 226, a third controller 330, and the 5 optical signal generator 124. Note that, in FIG. 7, components identical in structure to those shown in FIG. 5 are provided with the same reference numerals. With reference to FIGS. 7 and 8a to 8d, the operation of the optical amplifying device according to the third embodiment is described below.

10 [0045] The optical amplifying device 3000 is provided with an input optical signal having a waveform  $\lambda_1$  and an amplitude  $\alpha$ . This optical signal carries burst-like binary digital data. FIG. 8a shows the waveform of this optical signal.

[0046] The optical brancher 110 branches the received 15 optical signal in two. The logic level determination unit 226 determines the level of the binary digital data carried on one optical signal outputted from the optical brancher 110. The third controller 330 generates a control electrical signal based on a determination made by the logic level determination unit 226. The 20 generated control electrical signal has pulses with the amplitude  $\alpha$  and a width  $A_2$ , for example. Every time when the logic level determination unit 226 determines that the value of the data continuously indicates "0" for more than the predetermined time  $A_1$ , the pulse is outputted. The time  $A_1$  is predetermined based 25 on a relaxation time constant of the optical amplifier 116 and

other factors. Based on this control electrical signal, the optical signal generator 124 produces a dummy optical signal having the wavelength  $\lambda d$ . FIG. 8b shows the waveform of this dummy optical signal.

5 [0047] On the other hand, the other optical signal outputted from the optical brancher 110 is delayed by the delay unit 112 for a predetermined time, and then forwarded to the optical multiplexer 114. Here, the predetermined time is a time required for the one optical signal outputted from the optical brancher 10 110 to go through the logic level determination unit 226, the third controller 330, and then the optical signal generator 124 to become the dummy optical signal. The optical multiplexer 114 multiplexes the optical signal from the delay unit 112 and the dummy optical signal from the optical signal generator 124 15 together, and then produces a multiplexed optical signal. FIG. 8c shows the waveform of the multiplexed optical signal.

[0048] The effects of optical surges that occur when the input optical signal is changed in level from 0 to  $\alpha$  become larger as the period at the level 0 before the change is longer. 20 Therefore, if the no-data period continues for more than the predetermined time  $A1$ , the input optical signal is multiplexed with the dummy optical signal so that the no-data period of the multiplexed optical signal provided to the optical amplifier 116 does not continue for more than the time  $A1$ . Thus, the effects 25 of optical surges at amplification can be suppressed within a

permissible range.

[0049] The optical amplifier 116 amplifies the multiplexed optical signal. At this time, as shown in FIG. 8c, a period during which the multiplexed optical signal is at the "0" level is, at 5 most, the time A1.

[0050] After amplification, similarly to the first embodiment, the optical filter 118 separates the optical signal of the wavelength  $\lambda_1$  from the amplified optical signal. FIG. 8d shows the waveform of the separated optical signal.

[0051] In the present embodiment, the pulse width A2 is fixed, but may be variable if, for example, the pulses of the dummy optical signal overlap with the data period of the input optical signal. In such case, pulses are changed to be shorter in width for preventing the overlapping.

[0052] As described above, according to the third embodiment, the no-data period of the multiplexed optical signal provided to the optical amplifier 116 is controlled so as to become the time A1 at most. Thus, the effects of optical surges at amplification can be suppressed within a permissible range. Moreover, the 20 average optical power of the optical signal provided to the optical amplifier 116 is significantly smaller than that in the conventional device shown in FIG. 19. Thus, more amplification gain can be obtained.

[0053] Note that, in the second and third embodiments, the 25 input optical signal is a burst optical signal. Alternatively,

similarly to the case in the first embodiment, an arbitrary optical signal can be amplified.

[0054] Furthermore, in the second and third embodiments, the input optical signal has a single wavelength, that is, only the 5 wavelength  $\lambda_1$ . Similarly, if optical signals with different wavelengths  $\lambda_1$  to  $\lambda_n$  are provided in a time-division manner, for example, these optical signals can be amplified without degradation in waveform. In this case, however, the wavelength  $\lambda_d$  of the dummy optical signal has to be different from any of 10 the wavelengths  $\lambda_1$  to  $\lambda_n$ .

[0055] Still further, in the second and third embodiments, the optical filter 118 is used for the purpose of separating the optical signal of the wavelength  $\lambda_1$  from the amplified optical signal. Alternatively, an optical router may be used to achieve 15 the same purpose.

[0056] Still further, in the second and third embodiments, based on the determination made by the logic level determination unit 226, the second and third controller 228 and 330 generate the control electrical signal. Alternatively, for example, the 20 control electrical signal may be generated based on an electrical signal to be carried on the input optical signal.

[0057] (Fourth Embodiment)

FIG. 9 is a block diagram showing the structure of an optical amplifying device according to a fourth embodiment of the present 25 invention. An optical amplifying device 4000 includes a

semiconductor laser 432, a controller 434, the optical amplifier 116, and the optical filter 118. Note that, in FIG. 9, components identical in structure to those shown in FIG. 1 are provided with the same reference numerals. With reference to FIGS. 9, 10a, and 5 10b, the operation of the optical amplifying device according to the present embodiment is now described.

[0058] The optical amplifying device 4000 is provided with an input optical signal having a waveform  $\lambda 1$ . This optical signal carries burst-like binary digital data. FIG. 10a shows the 10 waveform of this optical signal.

[0059] The semiconductor laser 432 is controlled by the controller 434 so as to produce an optical signal having a wavelength  $\lambda d$  and identical in amplitude of the received optical signal having the wavelength  $\lambda 1$ . The semiconductor laser 432 15 is implemented as a distributed Bragg reflector (DBR) type semiconductor laser, for example. Such semiconductor laser has characteristics of, when an optical signal having a wavelength different from that of the semiconductor laser is externally provided thereto, suppressing oscillation thereof and 20 transmitting this externally-provided optical signal.

[0060] In other words, while the input light with wavelength  $\lambda 1$  to the semiconductor laser 432 is 0 in optical power, that is, while the optical power is 0 during both of the data and no-data periods shown in FIG. 10a, the semiconductor laser 423 produces 25 an optical signal of predetermined power having a wavelength

$\lambda_d$  under the control of the controller 434. On the other hand, while the input light to the semiconductor laser 432 is not 0 in optical power, the semiconductor laser 432 is suppressed in oscillation in response to the optical power. Therefore, the 5 waveform of the optical signal having the wavelength  $\lambda_d$  outputted from the semiconductor laser 432 becomes the inverted one of the input light, as shown in FIG. 10b. This optical signal of the wavelength  $\lambda_d$  corresponds to the dummy optical signal in the above-described conventional device and optical amplifying 10 device according to the first embodiment.

**[0061]** From the semiconductor laser 432, the light of the wavelength  $\lambda_1$  transmitted therethrough and the above-stated dummy optical signal of the wavelength  $\lambda_d$  are both outputted. As stated above, the light and the dummy optical signal are 15 inverted in waveform to each other. Therefore, the light outputted from the semiconductor laser 432 is constant in optical power.

**[0062]** The light outputted from the semiconductor laser 432 is amplified by the optical amplifier 116. At this time, the light 20 provided to the optical amplifier 116 is approximately constant in optical power, and therefore optical surges do not occur. After amplification, the optical filter 118 passes the optical signal of the wavelength  $\lambda_1$ .

**[0063]** As described above, in the fourth embodiment, the 25 optical signal of the wavelength  $\lambda_1$  to be amplified is provided

to the semiconductor laser 432 oscillating with the wavelength  $\lambda_d$  that is different from the wavelength  $\lambda_1$ . Thus, an optical signal constant in optical power and composed of the input optical signal superposed with the dummy signal is produced. Therefore,

5 the optical amplifying device capable of carrying out optical amplification without degradation in waveform can be achieved in a more simplified structure, compared with the above-described conventional device and the optical amplification device according to the first embodiment.

10 [0064] In the present embodiment, the input optical signal is a burst optical signal. Alternatively, an arbitrary optical signal can be amplified.

[0065] Furthermore, in the present embodiment, the input optical signal has a single wavelength, that is, only the 15 wavelength  $\lambda_1$ . Similarly, if optical signals with different wavelengths  $\lambda_1$  to  $\lambda_n$  are provided in a time-division manner, for example, these optical signals can be amplified without degradation in waveform. In this case, however, the wavelength  $\lambda_d$  of the dummy optical signal has to be different from any of 20 the wavelengths  $\lambda_1$  to  $\lambda_n$ .

[0066] Still further, in the present embodiment, the optical filter 118 is used for the purpose of separating the optical signal of the wavelength  $\lambda_1$  from the amplified optical signal. Alternatively, an optical router may be used to achieve the same 25 purpose. If the optical router is used, the dummy optical signal

may be used for data transmission or feedback control. Described below are modification examples according to the present embodiment, as fifth and sixth embodiments.

**[0067] (Fifth Embodiment)**

5 FIG. 11 is a block diagram showing the structure of an optical amplifying device according to the fifth embodiment of the present invention. An optical amplification device 5000 includes the semiconductor laser 432, the controller 434, the optical amplifier 116, and a first optical router 536. Note that, 10 in FIG. 11, components identical in structure to those in FIG. 9 are provided with the same reference numerals. With reference to FIGS. 11 and 12a to 12c, the operation of the optical amplifying device according to the present embodiment is now described. Note that the fifth embodiment is different from the fourth only in 15 that the first optical router 536 is provided instead of the optical filter 118. Therefore, the other components are not described in detail herein.

**[0068]** The optical amplifying device 5000 is provided with an input optical signal having a waveform  $\lambda 1$ . FIG. 12a shows 20 the waveform of this optical signal. Similarly to the fourth embodiment, the optical signal transmitted through the semiconductor that oscillates with a wavelength  $\lambda d$  is multiplexed with a dummy optical signal of the wavelength  $\lambda d$ , and then amplified by the optical amplifier 116.

25 **[0069]** The amplified optical signal is provided to the first

optical filter 536. The first optical filter 536 has first and second output ports each having transmittance characteristics as shown in FIG. 13a. Out of the amplified optical signal having a spectrum shown in FIG. 13b, the first optical router 536 outputs 5 the optical signal of the wavelength  $\lambda 1$  from the first output port and the dummy optical signal of the wavelength  $\lambda d$  from the second output port. FIG. 12b shows the waveform of the optical signal outputted from the first output port, while FIG. 12c shows that of the optical signal outputted from the second output port.

10 [0070] As evident from FIGS. 12b and 12c, the optical signals outputted from the first and second output ports are inverted in waveform, but these signals carry the same information. Therefore, by transmitting both of the optical signals, the information identical to that carried on the input optical signal 15 can be transmitted.

[0071] As such, in the fifth embodiment, not only the optical signal of the wavelength  $\lambda 1$  to be amplified but also the dummy optical signal of the wavelength  $\lambda d$  is used for data transmission. Thus, the generated optical signals can be utilized more 20 effectively.

[0072] In the present embodiment, the input optical signal is a burst optical signal. Alternatively, an arbitrary optical signal can be amplified.

[0073] Furthermore, in the present embodiment, the input 25 optical signal has a single wavelength, that is, only the

wavelength  $\lambda_1$ . Similarly, if optical signals with different wavelengths  $\lambda_1$  to  $\lambda_n$  are provided in a time-division manner, for example, these optical signals can be amplified without degradation in waveform. In this case, however, the wavelength 5  $\lambda_d$  of the dummy optical signal has to be different from any of the wavelengths  $\lambda_1$  to  $\lambda_n$ .

[0074] In the present embodiment, the first optical router 536 has two output ports. Alternatively, the first optical router 536 may have three or more output ports for outputting lights of 10 the wavelengths  $\lambda_1$  to  $\lambda_n$  and  $\lambda_d$ .

[0075] Here, consider a case where the optical amplifying device 5000 according to the present embodiment is used to construct a system as shown in FIG. 14. If a distance  $L_1$  between the optical amplifying device 5000 and a first optical receiver 15 30 is different from a distance  $L_2$  between the optical amplifying device 5000 and a second optical receiver 32, optical signals of wavelengths  $\lambda_1$  and  $\lambda_d$  both outputted from the optical amplifying device 5000 are disadvantageously differed in transmission characteristic (S/N ratio), even though they are identical in 20 amplitude.

[0076] To get around the above problem, if the distance  $L_1$  is longer than the distance  $L_2$ , the controller 434 controls the dummy optical signal of the wavelength  $\lambda_d$  outputted from the semiconductor laser 432 to be smaller in amplitude than the 25 optical signal of the wavelength  $\lambda_1$  to be amplified. Thus, the

same transmission characteristics can be observed in these optical signals and, by extension, in the system as a whole.

[0077] (Sixth Embodiment)

FIG. 15 is a block diagram showing the structure of an optical amplifying device according to the sixth embodiment of the present invention. An optical amplifying device 6000 includes the semiconductor laser 432, the controller 434, the optical amplifier 116, and the first optical router 536. Note that, in FIG. 15, components identical in structure to those shown in FIG. 11 are provided with the same reference numerals. With reference to FIG. 15, the operation of the optical amplifying device according to the present embodiment is now described. The optical amplifying device according to the sixth embodiment is different from that according to the fifth only in that the optical signal of the wavelength  $\lambda_d$  outputted from the first optical router 536 is used not for transmission but for control of the output light from the semiconductor laser 432. Therefore, the other components are not described in detail herein.

[0078] The optical signal of the wavelength  $\lambda_d$  outputted from the first optical router 536 in a manner similar to that in the fifth embodiment is provided to the controller 434. The controller 434 monitors this optical signal to control the semiconductor laser 432 so that the oscillation wavelength thereof becomes the wavelength  $\lambda_d$  and that the dummy optical signal from the semiconductor laser 432 becomes equal in amplitude

to the optical signal of the wavelength  $\lambda 1$  to be amplified.

**[0079]** In general, semiconductor lasers are feedback-controlled based on an output light therefrom. However, in the present embodiment, the output light from the semiconductor laser

5 432 includes the light of the wavelength  $\lambda 1$  and the dummy optical signal of the wavelength  $\lambda d$ , and therefore cannot be referred to for feedback control. For this reason, in the present embodiment, the first optical router 536 separates the controller 434 with the optical signal of the wavelength  $\lambda d$  from the 10 amplified optical signal for feedback control.

**[0080]** As described above, according to the present embodiment, the optical signal of the wavelength  $\lambda d$  outputted from the first optical router 536 is monitored. Thus, in addition to the effects similar to those in the fourth embodiment, the 15 optical amplifying device according to the fifth embodiment has such an effect as that the output light from the semiconductor laser 432 can be controlled more accurately.

**[0081]** With reference to FIGS. 16, 17a, and 17b, described is a system in which an optical signal is amplified by an optical 20 amplifying device and then again amplified for long-distance transmission

**[0082]** (Seventh Embodiment)

FIG. 16 is a block diagram showing the structure of an optical transmission system according to a seventh embodiment of 25 the present invention. The optical transmission system includes

an optical amplifying device 7000, second optical amplifiers 40a and 40b, and optical filters 50a and 50b. The optical amplifying device 7000 includes semiconductor lasers 732a and 732b, controllers 734a and 734b, an optical multiplexer 738, the first 5 optical amplifier 116, and a second optical router 736. Note that the first optical amplifier 116 shown in FIG. 16 is identical in structure to the optical amplifier 116 shown in FIG. 11. The operation of the present optical transmission system is now described below.

10 [0083] The optical amplifying device 7000 is provided with two optical signals having different wavelengths, one with a wavelength  $\lambda 1$  and the other with a wavelength  $\lambda 2$ . The optical signal of the wavelength  $\lambda 1$  is provided to the semiconductor laser 732a, which is controlled by the controller 734a, and then 15 multiplexed with a dummy optical signal of a wavelength  $\lambda d1$ . On the other hand, the optical signal of the wavelength  $\lambda 2$  is provided to the semiconductor laser 732b, which is controlled by the controller 734b, and then multiplexed with a dummy optical signal of a wavelength of  $\lambda d2$ .

20 [0084] Output lights from the semiconductor lasers 732a and 732b are multiplexed each other by the optical multiplexer 738, and then amplified by the first optical amplifier 116. At this time, the output lights from the semiconductor lasers 732a and 732b are constant in optical power and, accordingly, an output 25 light from the optical multiplexer 738 is also constant in optical

power. Therefore, optical surges at optical amplification do not occur in the first optical amplifier 116.

**[0085]** The amplified optical signal is provided to the second optical router 736. The second optical router 736 has 5 first and second output ports, and is structured as an AWG (Arrayed Wave Guide) having cyclic transmittance characteristics as shown in FIG. 17a. Of the input optical signal having a spectrum shown in FIG. 17b, the second optical router 736 outputs, from the first output port, the optical signal of the wavelength  $\lambda 1$  to be 10 amplified and the dummy optical signal of the wavelength  $\lambda d 1$  and, from the second output port, the optical signal of the wavelength  $\lambda 2$  to be amplified and the dummy optical signal of the wavelength  $\lambda d 2$ .

**[0086]** The optical signal outputted from the first output 15 port is again amplified by the second optical amplifier 40a in the course of transmission through an optical fiber. The optical signal inputted to the second optical amplifier 40a is constant in optical power, like the output light from the semiconductor laser 732a. Therefore, optical surges at optical amplification 20 do not occur in the second optical amplifier 40a. The amplified optical signal is provided to the optical filter 50a that passes the optical signal of the wavelength  $\lambda 1$ .

**[0087]** Similarly, the optical signal outputted from the second output port is again amplified by the second optical 25 amplifier 40b, and then provided to the optical filter 50b that

passes the optical signal of the wavelength  $\lambda 2$ .

[0088] As described above, according to the present embodiment, when the amplified optical signal is transmitted through a router, the input optical signal and the dummy optical signal are both outputted from the same port for transmission. Therefore, optical surges do not occur when the optical signal from the router is again amplified by another optical amplifier. Thus, amplification can be carried out twice or more without further requiring such device as the optical amplifying device 10 4000 shown in FIG. 9 for suppressing optical surges. Consequently, the system can be simplified in structure.

[0089] While the invention has been described in detail, the foregoing description is in all aspects illustrative and not restrictive. It is understood that numerous other modifications 15 and variations can be devised without departing from the scope of the invention.